10-1

ALLEN MATKINS LECK GAMBLE & MALLORY LLP
DAVID L. OSIAS
JEFFREY R. PATTERSON
MARK J. HATTAM
501 West Broadway, Ninth Floor
San Diego, California 92101-3577
Phone: (619) 233-1155
Fax: (619) 233-1158

HORTON, KNOX, CARTER & FOOTE
JOHN PENN CARTER
895 Broadway, Suite 101
El Centro, CA 92243
Telephone (760) 352-2821

Attorneys for Petitioner
Imperial Irrigation District

STATE WATER RESOURCES CONTROL BOARD

STATE OF CALIFORNIA

IMPERIAL IRRIGATION DISTRICT and SAN DIEGO COUNTY WATER AUTHORITY, Petitioners.	**STATEMENT OF EXPERT QUALIFICATION AND WRITTEN TESTIMONY OF DR. WOLDEZION MESGHINNA IN SUPPORT OF IID-SDCWA JOINT LONG-TERM TRANSFER PETITION**

WRITTEN TESTIMONY OF DR. WOLDEZION MESGHINNA

1. My name is Dr. Woldezion Mesghinna and I am the president and principal engineer of Natural Resources Consulting Engineers, Inc. ("NRCE"), an international civil, environmental, and water resources consulting firm. Though we have offices in Eritrea (Africa), California, and New Mexico, our main office is located in Fort Collins, Colorado, at 131 Lincoln Avenue, Suite 300.

2. I have my doctorate in Irrigation & Drainage Engineering, and a master's degree in Civil Engineering. I have over 31 years of experience in civil, irrigation, and water resources engineering work in the U.S. and overseas. Copies of my Curriculum Vitae and that of my associate Dr. Assad Safadi, who was my chief assistant on the Imperial Irrigation District ("IID") project discussed below, are attached to this testimony as Exhibit "A." They accurately reflect our expert qualifications and are incorporated herein. Our most recent work product is an extensive report on IID water use entitled, "Assessment of Imperial Irrigation District's Water Use" ("Water Use Report"). A true and accurate copy is attached to this testimony as Exhibit "B," and is incorporated herein. The following testimony is provided under oath, as specified at the end of this document.

3. The purpose of my testimony is to provide the State Water Resources Control Board ("SWRCB") and its staff with a summary of the research and opinions developed by myself and NRCE under my supervision, as stated in more detail in the Water Use

Report and in our earlier report on IID water conservation entitled, "History of Water Conservation Within the Imperial Irrigation District," a true and correct copy of which is attached as IID Exhibit "3" and is incorporated herein ("Water Conservation Report"). Both the Water Use Report and the Water Conservation Report represent NRCE's analysis and opinion of IID water use and water conservation history. I will be present at the hearing to answer any questions the SWRCB might have concerning NRCE's work or opinions.

4. This testimony is organized by first presenting a short review of our engagement with IID, along with a summary of our conclusions, and then the general basis for our conclusions. Of course, the full text of my testimony and opinions is in the Water Use Report and the Water Conservation Report, with only the highlights touched on here.

A. GENERAL PROFESSIONAL BACKGROUND

5. Though the attached Exhibit "A" document details the professional qualifications of both NRCE and myself, it may be helpful to the SWRCB for me to quickly summarize such here.

6. I received my doctorate in Irrigation and Drainage engineering from Utah State University, and I have a master's in Civil Engineering (Hydrology and Hydraulics) from Cornell University, as well as a bachelor of science in civil engineering from Cornell. I am a registered professional engineer in four states (California, Colorado, Wyoming, and Arizona).

7. I have extensive experience analyzing water resources issues, and testifying about such issues for many clients. Though the projects I have worked on are voluminous and are

detailed more fully in my attached Curriculum Vitae, some sample projects include: testimony on behalf of the Bureau of Indian Affairs and the U. S. Department of Justice in the Bighorn River system adjudication in Wyoming; testimony regarding the Yakima River tributaries in Washington; testimony for the U.S. Department of Justice regarding the lower Colorado River and the quantification of Indian water rights; testimony for the U.S. Department of Justice for general stream adjudications on numerous streams in Arizona, and I have been designated as an expert witness on various river basins in New Mexico, California, Washington, Nevada, Montana, Idaho, and Utah; water hydrology studies for numerous water rights holders across the West; development of water use plans for various irrigation projects; and operational management analysis of various river basins in the Western United States.

8. I formed NRCE in 1989, and since that time it has become a large and accomplished engineering firm focusing on water use issues. Our professional staff consists of 30 persons, five of whom have doctorates, and most of whom have various degrees and/or licenses in engineering fields. The attached Exhibit "B" Water Use Report lists our staff on page 6 of Appendix 1.

B. <u>NRCE'S ENGAGEMENT WITH IID</u>

9. NRCE was engaged by IID for two main purposes during two different time periods. First, in 1998 NRCE reviewed IID's water conservation history and prepared the Water Conservation Report. That report is summarized later in this testimony.

10. Then, over the past three years, NRCE reviewed IID's agricultural water use and irrigation efficiency. Our study involved extensive review of: (a) voluminous IID data, both from IID and other sources such as the Bureau of Reclamation; (b) other scientific studies of IID made in differing periods; (c) IID's delivery and on-farm systems; and (d) other irrigation districts located in the Lower Colorado River Basin. Additionally, NRCE did its own extensive IID fieldwork in 2000. The final product of our work is the attached Exhibit "B" Water Use Report, which includes our professional opinions on IID water use and is incorporated herein.

11. In total, between our work on the Water Use Report and the Water Conservation Report, NRCE utilized about 13,000 professional man hours to develop a comprehensive overview of IID's water use and conservation history, and to determine whether IID's water use was reasonable and beneficial. We not only reviewed all of IID's applicable records and did our own fieldwork, but we also reviewed and analyzed over 100 applicable professional publications and reports in completing our research.

C. <u>NRCE WATER USE REPORT</u>

12. NRCE performed a detailed analysis of IID's water supply, demand, delivery systems and irrigation, using records from 1988 to 1997 as well as a comparative water use study of several other irrigation districts located within the Southwest and the Lower Colorado River Basin. We also conducted our own field evaluation in 2000. The 1988 to 1997 study period was the most recent 10-year period with complete and extensive data

available when we commenced the scope of work encompassed in the Water Use Report.

13. Our conclusions about IID's water use are predicated upon a number of factors, the most important of them are summarized here:

a) During the study period (1988-1997), IID's on-farm efficiency averaged 83%, while its overall efficiency was about 74%. In other words 83% of the water delivered to the headgates of farmers was used for crop evapotranspiration (ET), leaching, and other crop production uses. The California Department of Water Resources (DWR) assumes that California's statewide on-farm irrigation efficiency will be 73% by the year 2020 and could reach 80% through better irrigation management and improved facilities (DWR 1998). The irrigation efficiency of IID has thus already surpassed the State's future efficiency estimate, 20 years ahead of time. To attain such irrigation efficiency, IID growers often apply lower amounts of water than they really need, thus limiting tailwater, but also accepting lower yields.

b) The irrigation efficiency of IID is so high that even other irrigation projects that are served by some of the most technologically advanced irrigation systems, including drip irrigation, exhibit only about the same level of irrigation efficiency. To the extent that water loss occurs in IID, it is generally justified as a corollary to farming in a hot climate with heavy cracking soils.

c) IID's average conveyance and distribution efficiency from 1988 to 1997 was determined to be approximately 89%. In other words, about 11% of the water diverted by IID from the Colorado River was lost to evaporation and unrecovered seepage and spills rather than being delivered to farm headgates. The 89% conveyance efficiency is high, especially given the size of IID's irrigation project and the complexities of its water distribution system.

d) Tailwater is a vital and necessary component of Imperial Valley irrigation. The cracking nature and low permeability of the majority of IID soils, and the fact that growers have to attempt to apply adequate irrigation water on the entire field, result in tailwater at the tail end of the field. In fact, due to the low permeability of the heavy cracking soils in IID, it is often difficult to adequately leach salts from the soil during regular irrigation applications. The nature of most of IID's soils requires more leaching water than stated in traditional leaching formulae, which equations are more applicable to non-cracking soils. Though both horizontal and vertical leaching occur during regular irrigation, only a portion of the salts in the soil are leached at such time, while the remaining portion remains in the root zone, thereby requiring additional leaching between crops.

e) When irrigation water is applied at the head of the field, it picks up salts from the soil as it moves to the lower end of the field. Based on field studies, it was determined that the salinity of the tailwater is about 30% higher than the water delivered at the head of the field, which indicates significant horizontal leaching is taking place in IID because of the nature of its soils.

f) During regular irrigation on IID's medium and heavy soils, based on field tests, only 4.5% of the applied water drains vertically, removing about 30% of the salt introduced by the irrigation water, while about 17% of the applied water ends up as tailwater that removes approximately 22% of the salt introduced by the irrigation water. This leaching process is compounded by the fact that the Colorado River, by the time it reaches IID, contains significantly increased mineral salt concentrations. Excess salts in light soils are more easily removed than salts in heavy cracking soils, such as those found in IID, because the permeability of the light soils is adequate for vertical leaching.

g) On many IID farms with medium and heavy cracking soils, it would be wise for growers to apply even more water during irrigation for leaching and crop consumptive use purposes than they currently do, because this would increase crop yields. However, since higher water application could result in higher tailwater, growers tend to apply barely enough water for crop use and for partial leaching of salts. As a result of insufficient leaching, some of the irrigated fields in IID, especially the lower end of those fields, become too saline for high crop production, thus decreasing the productivity of valuable acreage.

h) Based on field studies, during which the three processes of leaching for cracking soils (vertical leaching during crop irrigation, leaching irrigation between crops, and horizontal tailwater leaching during crop irrigation) were looked at, it was determined that approximately 0.73 acre-feet per acre is used for leaching on an annual basis. The leaching requirement for light soils was estimated to be about 0.58 acre-feet per acre per year. About 87% of IID irrigated lands have limited permeability in the root zone, while the remaining 13% are light soils.

14. Based on the above results and the other matters addressed in our report, it is our opinion at NRCE that the overall irrigation water use in IID at the present time is reasonable and beneficial. Despite its unique environmental conditions, IID has one of the highest on-farm irrigation efficiencies relative to the other irrigation districts served by the Lower Colorado River, and has a higher on-farm irrigation efficiency than the assumed expected efficiency by the State of California for the year 2020. Though IID has been criticized by some for its water use, in NRCE's opinion, such criticisms are

uninformed and unwarranted. A well studied look at IID's water usage evidenced that IID and its growers manage reasonably well in difficult environmental circumstances, and in fact could justify using more water for leaching and crop consumptive use than they currently utilize.

15. The following summary chart from the U.S. Bureau of Reclamation statistics (1990) showing comparative distribution system efficiencies illustrates IID's distribution efficiency relative to the other irrigation districts in the area:

Irrigation Project	Irrigated Area (Acres)	Distribution System Efficiency
Welton Mohawk IDD	60,324	90%
Imperial Irr. District	463,030	89%
Coachella Valley Water District	61,052	87%
Yuma Valley Division	45,761	73%
Salt River Valley	54,174	40%

16. It is obvious from the above statistics that despite having to irrigate about eight times more acreage than the other districts listed, and having a much older canal infrastructure than most, IID does better than almost all of them, and is within 1% of Wellton Mohawk. Further, even though the Coachella Valley Water District ("CVWD") has extensive buried pipelines in its conveyance system, IID still has a higher distribution efficiency.

17. Our general methodology in reaching the above conclusions as to the reasonableness of IID's water use can be briefly summarized as follows:

a) In evaluating IID's water use, we considered all inflows and outflows for IID, including measured inflows of the Colorado River diverted from the All-American Canal. We also measured inflows entering IID from Mexico, estimated minor inflows due to subsurface and local runoff, reviewed all measured outflows, and estimated minor subsurface and surface inflows into the Salton Sea. In addition, all the non-agricultural consumptive uses in IID were estimated. IID consumptive use was determined based on this information.

b) IID's water use was first analyzed by NRCE using the water balance method. A volume balance analysis was performed for the entire District as a system-wide unit, as well as two subsystems that include the conveyance and distribution level subsystem and the on-farm level subsystem. The primary objective in the water balance method approach is to estimate the total water consumptive use. This method is appropriate for the Imperial Valley because of the Valley's unique physical setting and hydrogeologic conditions as a closed basin.

c) Determination of the IID on-farm and overall irrigation system efficiencies required examination of irrigation water beneficially used. There are various uses of irrigation water that are beneficial in addition to directly satisfying crop water consumption demands. In IID, other beneficial uses of irrigation water include seedbed and land preparation, germination, cooling, and leaching for salinity control.

d) Development of realistic leaching estimates for IID required a detailed soil analysis, both from documentary records and in person. It also necessitated analyzing salt levels in the water, as well as reviewing climatic conditions and general farming practices. For the majority of soils in IID, given the characteristics of the soil water movements and the low permeability of the cracking soils, we concluded that the conventional leaching formulas are not applicable. The salinity of IID's water, coupled with the nature of its soils, requires higher amounts of leaching water than traditional formulae for non-cracking soils would conclude.

e) Our conclusions about the difficulties of salt leaching in IID are in accord with the majority of professional literature about agriculture in IID. To the extent we differ from some critics of IID, such as Dr. Marvin Jensen, it is with good cause. As explained in detail in Appendix 9 of our Water Use Report, Dr. Jensen made certain assumptions that did not account for leaching in medium and heavy cracking soils and changes in irrigation water salinity, which ultimately negated his conclusions.

18. In addition to our analysis of IID's water use, we also reviewed whether or not a proposed transfer of up to 200,000 acre-feet to the San Diego County Water Authority ("SDCWA"), with the corresponding change in place of diversion from Imperial Dam to the upstream Lake Havasu, would adversely affect other legal users of water.

19. We reviewed the historic water use of all Colorado River appropriators downstream of the Colorado River Aqueduct and above Imperial Dam, as well as the effect of a 200,000 acre-foot per year reduction on the All-American Canal. After reviewing all the data, we determined that at all times during the 10-year study period (1988-1997) there was sufficient hydraulic head at all diversion structures to deliver their normal capacity. We thus determined that IID's proposed transfer of 200,000 acre-feet of conserved Colorado River water to San Diego would have no meaningful adverse impact on other water right holders downstream of the proposed Lake Havasu diversion.

20. In recent months IID and various other water agencies have worked out an additional water transaction in which a potential 100,000 acre-feet per year might go to CVWD and/or MWD. Though our initial study did not include such a recent transaction, we were later asked by IID to determine if there would be any impact to other legal users of water if some or all of that 100,000 acre-feet per year were to go to CVWD. Based upon all of the work we performed, the answer is clearly that there would be no impact on other legal users of water. All Colorado River water that currently flows to CVWD does so via IID's diversion at Imperial Dam, and it is not until the water

has traveled some miles down IID's All American Canal that CVWD water is diverted into the Coachella Canal. To the extent that IID diverts more water into the Coachella Canal and lets less flow on into IID, this does not affect any other Colorado River users. We were not asked to express an opinion on whether or not a diversion to MWD of up to another 100,000 acre-feet per year into the Colorado River Aqueduct would adversely affect other Colorado River water right holders, and we understand that MWD would not receive any water under the proposed settlement unless CVWD first declined it.

21. The following is a very short summary of our hydrology work, and our Water Use Report provides the detailed hydrology:

a) U.S. Bureau of Reclamation data was used as a basis for determining the various users and their diversion and return amounts in the reaches of the Colorado River and the All American Canal.

b) The study period from 1988 to 1997 was selected so there would be flow variations representative of the long-term conditions in the study area. It was important for the study period to include extreme years of low river flows since further reduction of river flow in low flow conditions may deplete the water supplies of some of the river users. The historical flow records from 1935 to 1997 show that the lowest Parker Dam annual release (5,533,851 acre-feet) was in 1993 and is thereby covered in the study period.

c) NRCE's flow adequacy analysis shows that during the 10-year study period there was sufficient water in the system to meet all the demands of the other water right holders even though the Colorado River supply was hypothetically reduced by 277 cfs for the IID water transfer. The results of the hydraulic analysis indicate that the reduction in flow would not hydraulically affect the deliveries of the normal historical diversions through the various turnout structures along the Colorado River and the All-American Canal. Hence, NRCE has determined that the transferring of IID's conserved water to San Diego has no meaningful impact on the other water right holders with respect to supply and hydraulics.

D. <u>NRCE WATER CONSERVATION REPORT</u>

22. In addition to the Water Use Report, NRCE earlier performed a review of IID's conservation history, the Water Conservation Report, which is IID Exhibit "3," and which contains our research and opinions regarding IID's past conservation. The purpose of this analysis was to review the conservation history in IID, determine how much water conservation had been achieved to date, and prepare for the more extensive Water Use Report. It was a reconnaissance-level review, as opposed to the more extensive water use analysis that was to follow. Nonetheless, we believe it will be helpful to the SWRCB in its hearings related to the proposed water transfer from IID to San Diego, and acquisition by CVWD.

23. Here is a short summary of what we found in our review of IID's conservation history, all of which is explained in more detail in our report:

a) IID's current irrigation technology and conservation programs include concrete canal and ditch lining, laser precision land leveling (where applicable), regulating reservoirs and interceptor canals, seepage recovery programs, tile drains, and automated delivery systems.

b) By the mid-1980's, IID farmers had lined 80% of their ditches with concrete; today over 90% of the ditches are lined. Ditch lining conserves water by reducing seepage and it gives farmers more control over the amount of water delivered to the fields. However, the cost to IID farmers is roughly $192 million[1] for the 2,600 miles of farm head ditches.

c) In order to keep the water table below the root zone and allow for critical leaching to take place, IID farmers have installed about 34,000 miles of tile drains. Tile drain installations have collectively cost IID farmers at least $224 million in present day dollars.

d) In certain areas where it can be effective, IID farmers have spent $150 million[2] on initial land leveling, and spend $30 to $60 per acre on leveling touch-ups every three to five years.

e) Typically, farmers spend as much on water management labor as they do to purchase water.

[1] Using 1998 costs.
[2] Using 1998 costs.

f) Some IID farmers have also been able to invest in techniques such as ponding water on the tail of a field during land preparation; controlling furrow inflow and outflow to reduce tailwater runoff; reusing tailwater; sprinkler and drip irrigation; and deep tillage. However, these methods are generally costly and are not necessarily suited to all soils, parcels, and/or crops.

g) IID has made significant improvements to its automated delivery system, appointed a Water Conservation Advisory Board to make recommendations regarding water conservation, and has installed several tailwater recovery systems. IID also provides zanjero and hydrographer training at Cal Poly San Luis Obisbo, requires certification of all farmers handling IID irrigation deliveries, and in the past 15 years has commissioned or participated in numerous studies of potential water conservation.

h) When IID found that two areas of its major canals had sandy soil, it spent $495,000 to install recovery drains in those sections. The recovery drains pump seepage water back into the canals and collectively conserve 24,000 acre-feet of water annually.

i) IID has lined over 1,169 miles[3] of its canals.

j) IID built four regulating reservoirs at a cost of $3 million. The purpose is to capture excess water that a farmer has ordered, so it does not have to spill out of the canal; instead, it is stored in a regulating

[3] This includes the 200 miles lined under the 1988 MWD Agreement.

reservoir. The savings from these four reservoirs amounts to roughly 18,000 acre-feet of water per year.

k) In order to prevent aquatic weeds from clogging drains and canals, IID raises and introduces 20,000 sterile weed-eating Triploid Grass Carp into the All-American Canal each year.

l) With MWD's funding, IID has successfully implemented numerous conservation measures. For example, IID lined an additional 200 miles of canals, conserving 26,000 acre-feet of water in 1997; replaced wooden headgates with non-leak metal ones; and constructed six regulating reservoirs to capture excess canal water, two of which collectively conserved 9,700 acre-feet of water in 1997. Additionally, as part of the MWD program: (1) IID built a Water Control Center to house its Supervisory Control and Data Acquisition System ("SCADA"). The SCADA system monitors flows and water levels in the major canals and reservoirs and allows remote operation of 95 water control structures (i.e. delivery gates and main canal gates) to decrease canal spills and provide more efficient water deliveries; (2) IID constructed three interceptor canals. An interceptor canal catches excess lateral water that would otherwise spill into a drain. The interceptor carries the excess water to a regulating reservoir, where it can be used to meet deliveries. In 1997, two of these interceptor canals conserved 6,650 and 8,460 acre-feet of water, respectively; (3) as a result of increased technology and water system upgrades, IID farmers can now order water in 12-hour time blocks. This system not only provides farmers more flexibility, but it also helps farmers conserve water by encouraging them to more accurately match their water orders to existing soil and crop needs; and (4) IID constructed twenty-five tailwater recovery systems. These systems collect tailwater from small field reservoirs and pump the water back to the head of the field.

m) IID participates in federal and state conservation programs. For example, IID supports the California Irrigation Management Information System ("CIMIS"). CIMIS' automated weather stations collect temperature, solar radiation, humidity, and wind speed data, which are used to estimate crop evapotranspiration. IID has also provided irrigation scheduling workshops and has participated in a number of irrigation research projects at the Imperial Valley USDA Irrigated Desert Research Station. IID has supported the USDA Natural Resources Conservation Service and has funded conservation-related research programs through the University of California Cooperative Service.

24. The above summaries of NRCE's work really just give the barest outlines of our analysis. I urge the SWRCB and its technical staff to read the NRCE reports, particularly the Water Use Report, to fully understand our opinion that IID is irrigating efficiently in difficult circumstances, and is thus reasonably and beneficially utilizing its water rights.

I declare under penalty of perjury under the law of the state of California that the foregoing is true and correct. Executed on March, 21, 2002, at Fort Collins, Colorado.

DR. WOLDEZION MESGHINNA

Woldezion Mesghinna, Ph.D., P.E. *President and Principal Engineer*

Education

Ph.D., Irrigation & Drainage Engineering,
Utah State University; Logan, Utah; December 1978

M.E., Civil Engineering (Hydrology & Hydraulics),
Cornell University; Ithaca, New York; May 1973

B.S., Civil Engineering,
Cornell University; Ithaca, New York; May 1972

Professional Registrations

Professional Civil Engineer, California, #C-031962, 1980
Professional Civil Engineer, New Jersey, #GE 38267, 1994
Professional Civil Engineer, Colorado, #30081, 1994
Professional Civil Engineer, Wyoming, #PE6787, 1994
Professional Civil Engineer, Arizona, #28952, 1995

Experience

President and Principal Engineer; Natural Resources Consulting Engineers, Inc.; Fort Collins, Colorado; March 1989-Present: Dr. Mesghinna formed Natural Resources Consulting Engineers, Inc. (NRCE) in 1989.
Water Supply Studies

- Comprehensive water supply analysis of several major rivers including the Deschutes, Melotious, Crooked, and Warm Springs, and Shitike Creeks in Oregon. The various impacts of upstream water users on these streams were determined, especially the Deschutes River. The results of this study helped the Warm Springs Tribes craft their negotiated settlement water claims and conduct actual negotiations with the State of Oregon and the U.S. government.
- Quantified the water supply of the Sif Oidak District of the Tohono O'odham Nation in Arizona. This involved the determination of irrigable acreage and water requirements, the investigation of the extent of past floods on reservation areas, and the evaluation of the impact of regional urbanization on flood frequency. The effects of groundwater pumping on the area's aquifers were also determined.
- Evaluated the impact of historic gold mining operations on water quantity and quality on the Fort Belknap Indian Reservation in Montana.
- Carried out operational management of the Wind River watershed in Wyoming including an analysis of reservoir systems, irrigation uses, and fishery water requirements.

- Quantified water requirements needed to restore and maintain historic wetland areas on the Duck Valley Indian Reservation in Idaho. The various water supply sources were analyzed and comprehensive water use plans were studied.
- Studied the irrigation return flow and depletion for the future lands of the Wind River Indian Reservation in Wyoming to quantify an in-stream flow water claim.
- Quantified present and future water uses for the Klamath Allottees Water Users Association and provided advice and counsel in matters relating to the adjudication/negotiation of water rights for the Association.
- Analyzed both surface water and groundwater resources within the Tule River Indian Reservation. This involved a study of the arability of Reservation lands, the determination of the available water supply of the Tule River, and the quantification of the water requirements for both agricultural and nonagricultural water uses.
- Provided technical direction and coordination of the Tribal Water Code development, the development of a river accounting model, and the performance of interim Tribal Water Engineer duties for the Fort Hall Indian Reservation.
- Completed an appraisal-level engineering design for a delivery and recharge facility including costs for a number of alternatives for the San Xavier Groundwater Recharge Project.
- Assessed the natural resources including historic and undepleted surface flows of the Jemez River, alluvial and deep groundwater irrigability of lands, consumptive use of the adaptable crops in the area, and based on engineering and economic feasibility of a comprehensive water development plan, the amount of water the Jemez Tribe would claim under a negotiated settlement scenario was determined.

Irrigation/Agriculture

- Planned and designed the rehabilitation and reconfiguration of the conveyance distribution and drainage systems for the Wind River Indian Irrigation Project and determined the amount of water that could be saved as well as the associated capital costs.
- Designed the Tohono O'odham Nation, Arizona 9B and Avra Valley Irrigation Systems. The suitability of these areas was determined for different types of irrigation systems and the designs of the water conveyance and on-farm systems proposed for the 9B farm were analyzed. Preliminary designs for the water conveyance and distribution systems associated with the irrigable acreage identified in the land classification of the Avra Valley site were developed.
- Completed a comprehensive Aligidir Irrigation Project Development Plan devised for the Gash River near the city of Tessenei, Eritrea. The plan determined a sustained available water supply, the irrigability of lands, an environmental impact assessment, and determined economic feasibility. Sediment traps, a diversion structure; conveyance and distribution systems; and an off-stream dam and reservoir were also planned.
- Completed a scheme for stream flow and climatic network locations within Eritrea and installed and trained local and Water Resources Department of Eritrea personnel to operate and maintain the equipment.

Water Supply/Irrigation Projects

- Measured seepage losses on all selected reaches of major canals on the Wind River Indian Reservation. Surface and subsurface conditions of private ditches were assessed, and a recommendation as to minimizing and/or avoiding water logging problems was made. A list of all irrigation structures in need of replacement or maintenance was prepared and a plan of action was suggested.
- Completed an extensive analysis regarding the available water supply conditions, flood hazards, and the land capability for irrigation purposes within the Fort Mojave and Colorado River Indian Reservations. the ultimate number of practicably irrigable lands under conditions of the 1960's were also determined. Dr. Mesghinna testified extensively in court to defend his findings.
- Performed a multipurpose study of the Tekezze-Setit River Basin. This included the estimation of available water supply, the development of land classification specifications, the location of various dam and reservoir sites along the river, the assessment of proposed irrigable lands, the determination of the criteria for the environmental study, the review of the final study, and the overall coordination of economics, mapping, hydropower, and geotechnical, conveyance, and distribution systems.
- Prepared a comprehensive water development plan for the Navajo, Hopi, and San Juan Southern Paiute Indian Reservations in Arizona. The tasks included determination of the undepleted flow of the Little Colorado River, availability of groundwater within the Coconino and Navajo Aquifers, present and historical irrigation water use determination, future irrigation engineering studies (both appraisal and feasibility level), feasibility-level M&I and recreation water development design and plans; and drainage engineering services. Dr. Mesghinna is presently serving as the technical coordinator of the federal studies pertaining to the adjudication of the Little Colorado River System.
- Analyzed the available surface water supply from the Owyhee River in Nevada and Idaho, specifically, the undepleted flow analysis was determined based on Reservoir operation, determination of the depletion due to agricultural and non-agricultural water uses, return flows, etc. The study was conducted as part of an irrigation and drainage development plan for the Duck Valley Indian Reservation in Idaho and Nevada.
- Acted as a lead engineer for the planning, design, and construction management and supervision of a 230 foot high RCC dam. The project also includes a 15 km long pipeline extending from the dam to the water treatment plant. The pipeline empties into a water treatment plant with a treated water capacity of 2000 m^3 located in the outskirts of Asmara, Eritrea. The entire project is nearing completion and is expected to be commissioned by May 2002.
- Conducted a reconnaissance comprehensive water development plan for the Eastern plains of Eritrea, including land classification for development of irrigation schemes, availability of surface and groundwater resources, investigation of suitable dams and reservoirs, and estimation of capital, operation, and maintenance costs.
- Evaluated the water resources of Rio Acoma in New Mexico, including groundwater and surface water supplies, present, historic, and future water uses for both agricultural and non-agricultural uses, and determination of natural flow of the River at a point near the Pueblo of Acoma.

Supervising Engineer; Stetson Engineers, Inc.; San Rafael, California; 1978-1988:
Dr. Mesghinna supervised hydrologic analysis and water supply investigations; determined agricultural water requirements; and designed irrigation systems.

Water Supply Studies

- Quantified the water resources and potential water requirements of the Fort Belknap Indian Reservation. This involved the development of a feasibility-level irrigation engineering study, the determination of water requirements, and the quantification of natural surface flow for reserved water rights litigation.
- Performed a water availability study of the Upper Missouri River and tributaries using the HEC-4 hydrologic model. This included the simulation of monthly stream flows for missing flow records and ungaged locations and river and reservoir system operation studies.
- Analyzed the reservoir system operation for several operating scenarios on both the Eel and Russian Rivers of California using the HEC-3 hydrologic model.

Irrigation/Agriculture

- Participated in the adjudication of the Big Horn River Systems of Wyoming and the agricultural system development plan including the design of a conceptual irrigation system and associated cost analysis, for approximately 60,000 acres. Also determined future and historic irrigation water requirements for the Wind River Indian Reservation.
- Performed several studies for the Fort Hall Indian Reservation in Idaho in connection with the "President's Water Policy Implementation 10-Year Plan for Review of Indian Water Claims", involving water supply, irrigation water requirements, and related studies. Provided technical assistance to the Tribes in connection with negotiations with the State of Idaho.

Water Supply/Irrigation Projects

- Conducted a surface water depletion study and engineered an agricultural development plan, including conceptual irrigation system design, for the Yakama Indian Reservation in Washington.
- Completed a comprehensive surface water hydrology study, including the determination of natural flow, water quality, and sedimentation, in connection with water rights litigation for the Jicarilla Indian Reservation, and the San Ildefonso, Santa Clara, San Juan, and Taos Pueblos of New Mexico.
- Completed a comprehensive water resource analysis, including hydrological analysis of the various streams and agricultural engineering study as part of the comprehensive water development plan for the Nez Perce Indian Reservation in Idaho.
- Calculated the available water supply for the Jemez River Indian Reservation including the determination of probable maximum flood for the design of a reservoir and spillway. Hydropower feasibility was also assessed .

Engineer; Woodward-Clyde Consultants; Clifton, New Jersey; 1973-1978:
Dr. Mesghinna worked on many projects requiring geotechnical and hydrological engineering evaluation and analysis.

- Analyzed the flooding potential of Sawmill River for the Yonkers City Urban Development Project.
- Investigated and evaluated groundwater resources for the development of groundwater in New Mexico.
- Designed a dewatering system for the installation of a subaqueous tunnel at the LNG Terminal of Cove Point, Maryland.

- Performed well testing and estimated groundwater characteristics for the cooling lake at Braidwood Nuclear Power Station in Illinois.
- Completed subsurface investigation, soil sampling, rock coring, and permeability testing for the Amos Dam of West Virginia.
- Reviewed and evaluated the timber pile foundation design and settlement for various structures located in the meadowlands of the New Jersey Sports Complex.
- Performed temperature-controlled creep load tests on steel pipe piles and designed piles for the Trans-Alaska Pipeline in Alaska.

International Experience

During the period from 1966 to 1970, Dr. Mesghinna was employed in Ethiopia as an engineer in the design, planning, and construction of various school buildings, clinics, and hospitals. These projects were sponsored by the Swedish International Development Authority (SIDA) and the United National High Commission for Refugees (UNHCR). He was first employed as a Site Supervisor for the construction of a school building, then as a District Engineer and Acting Regional Engineer in charge of three building sites. As such, he was responsible for the planning of all operations, supervision of construction, design and product development, contract development and construction agreements, the production of construction cost estimates, and the performance of site investigations and surveys.

Expert Witness Experience

Dr. Mesghinna successfully completed professional witness testimony on behalf of the Bureau of Indian Affairs and the U.S. Department of Justice (DOJ) in the adjudication of the Big Horn River System in Wyoming. His testimony concerned future and historic water requirements and future and historic irrigation system design for the Wind River Indian Reservation. Furthermore, Dr. Mesghinna completed testimony on behalf of the DOJ concerning the lower Colorado River, in which his task was to prove that the U.S. government had properly quantified the Indian reserved water rights in the early 1960's. More specifically, he provided testimony on flood analysis, land classification, and irrigation system selection/design. Dr. Mesghinna served as an expert witness on behalf of the DOJ for general stream adjudications on the Silver Creek, Upper Salt River, and San Pedro Drainage Basins in Arizona; the Walker River Basin in Nevada; the Little Colorado River Basin; the Zuni River Basin in New Mexico; and the San Jacinto River Basin in Southern California. Dr. Mesghinna has been instrumental in several water rights settlement negotiations in the Western United States and has helped to settle water rights claims amounting to more than three million acre-feet. Examples include the Fort Hall, Fort Peck, Warm Springs, Las Vegas Paiute and Fort McDowell Indian Reservations.

Relevant Computer Skills

- Hydrologic Models: Extensive computer programming experience in hydrologic modeling, including:
  - Development and testing of a crop yield prediction model
  - Development of various computer programs for:
    - Crop consumptive use determination
    - Irrigation system design
    - Irrigation pipe network design
    - Subsurface drainage design
    - Canal seepage analysis
    - Natural flow analyses for river basins
- Earned certificates of completion from the Agricultural Extension program of the University of California at Davis for water surface profile computation and flood hydrograph analysis computer programs using HEC-2 and HEC-1.

Awards and Honors

- College of Engineering "Distinguished Alumnus", Utah State University, 1992
- City of Richmond "Distinguished Service Award", Richmond, California, 1993

Languages

- Tigrignia (native)
- Italian
- Amharic

Assad Safadi, Ph.D.

Senior Vice President

Education

Ph.D., Agricultural and Irrigation Engineering,
Utah State University; Logan, Utah; April 1991

M.S., Soils and Irrigation,
University of Jordan; Amman, Jordan; February 1987

B.S., Soils and Irrigation,
University of Jordan; Amman, Jordan; January 1985

Experience

Senior Vice President; Natural Resources Consulting Engineers, Inc.; Fort Collins, Colorado; July 1991-Present:

Agriculture

- Identifies suitable crops and cropping patterns.
- Develops models to estimate crop water requirements for over twenty projects in New Mexico, California, Arizona, Idaho, Oregon, Nevada, Utah, and Washington.

Irrigation

- Designs irrigation systems and estimates irrigation efficiencies.
- Designs reconnaissance- and feasibility-level on-farm irrigation systems for Indian water rights cases in Nevada, Idaho, California, New Mexico, and Arizona.

Expert Witness Testimony

- *Testified on behalf of the United States on agricultural water use in Arizona v. Gila River (Arizona, 1995); United States v. Abousleman et al. (New Mexico, 1996 and 1999); and Washington State Department of Ecology v. Aquavella et al. (Washington, 1994).*

Water Resources

- Performs water quality analyses.
- Estimates natural flows and identifies diversion points.

Natural Resources

- Analyzes climatic parameters.
- Soil and land classifications.

Economics

- Economic feasibility analyses.
- Financial analyses/crop budgeting.

Water Rights Litigation

- Project manager on more than one dozen Indian water rights cases.
- Provides technical guidance to federal and Tribal attorneys during water rights litigation and/or negotiation cases.
- Coordinates the technical work among the various government

experts in the *Arizona v. Little Colorado River*, *United States v. Walker River Irrigation District*; *Mannatt v. United States*; and the *Soboba v. Metropolitan Water District* litigation cases.

- Lead technical expert in water rights negotiations for the Pueblos of Jemez in New Mexico, the Owens Valley Tribes in California, the Moapa Paiute Tribe in Nevada, and the Fort Yuma Indian Reservation in Arizona and California.
- Quantifies water claims.

Senior Vice President

- Lead technical negotiation expert for the United States in Soboba v. Metropolitan Water District (California), United States v. Walker River Irrigation District (California and Nevada), and United States v. Abousleman et al. (New Mexico).
- Responsible for delegating and coordinating the work load among the staff members at NRCE's Fort Collins and Berkeley offices.

Post-Doctorate Researcher/Teacher/Research Assistant; Department of Agricultural and Irrigation Engineering, Utah State University; Logan, Utah; January 1988-June 1991:

- Calibrated new crop coefficients for use with the Soil Conservation Service's modified Blaney-Criddle equation for various sites within the State of Utah.
- Lectured on crop yield modeling, development of irrigation scheduling models, and irrigation uniformity/yield interaction for a course on Field Irrigation Management.
- Helped develop computer programs for the calculation of crop evapotranspiration and pattern search techniques for crop coefficients derived from lysimeter research data collected from Utah, Idaho, and Wyoming.
- Worked on climatic data from Somalia.
- Attended and participated in Utah Experiment Station project meetings.
- Installed and programmed automated weather stations.

Teaching and Research Assistant; Department of Soils and Irrigation, University of Jordan; Amman, Jordan; September 1984-February 1987:

- Taught Principles of Soil Science, Fertilizers and Soil Fertility, and Soil Physics Labs.
- Taught on types and amounts of fertilizers to be applied and their application, as well as the analysis of soil and plant nutrients (N, P, K, and micronutrients).
- Demonstrated how to determine the physical properties of soils, reviewed field practices to be used in the calibration of neutron meters, and performed and demonstrated irrigation scheduling using tensiometers as well as various sampling techniques.
- Conducted laboratory analyses of the physical properties of soils (e.g., bulk density, hydraulic conductivity, and soil moisture characteristic curves).
- Conducted field experiments to study the effects of sewage sludge and chicken manure on sweet corn production and heavy metals content in soils and plants.

Relevant Computer Skills

- *Graphics Software:* Grapher, Surfer
- *Statistical Software:* TSP, LINDO
- *Programming Languages:* FORTRAN, BASIC

Languages

- Arabic (native)
- French

Awards and Honors

- King of Jordan "Top of the Class Award", B.S. Degree; University of Jordan, 1985
- King of Jordan "Top of the Class Award", M.S. Degree; University of Jordan, 1987
- College of Engineering "Distinguished Alumnus Award"; Utah State University, 1998

Publications

Safadi, A.S. "Determination of Water Supplied from the Jemez River System and the Nacimiento Creek to meet the crop demand of the Nacimiento Community Ditch Association (NCDA)." *Prepared for the U.S. Department of Justice*, Denver, Colorado, August 11, 1999.

Safadi, A.S. "Determination of Crop Water Requirements and Irrigation Water Requirements of Presently Irrigated Lands: Toppenish, Simcoe, and Satus Creeks Sub-basins, Yakama Indian Reservation, Yakima, Washington." *Prepared for the U.S. Department of Justice,* Washington, D.C., November 28, 1994.

—. "Yakima River and its Tributaries' Depletions, Yakama Indian Reservation, Yakima, Washington." *Prepared for the U.S. Department of Justice,* Washington, D.C., November 28, 1994.

—. "Crop Water Requirements for the Pomerene Water Users Association (PWUA), San Pedro River Watershed, Arizona." *Prepared for the U.S. Department of Justice,* Washington, D.C., September 28, 1994.

—. "Squash and Cucumber Yield and Water Use Models." Ph.D. Dissertation, Utah State University, Logan, Utah, 1991.

—. "Comparison of Water Use Efficiency Under Drip, Sprinkler, and Gravity Irrigation Systems." *Paper Presented to the University of California Cooperative Extension Service,* Holtville, California. 1990.

Safadi, A.S., and Hill, R.W. "Squash and Cucumber Irrigation-Yield Simulation Models." *Paper No. 90-2614 Presented at the American Society of Agricultural Engineers' Winter Meeting,* Chicago, Illinois. 1990.

Safadi, A.S. and Battikhi, A.M. "A Preliminary Study on the Effects of Soil Moisture Depletions Under Black Plastic Mulch and Drip Irrigation on Root Growth and Distribution of Squash in the Central Jordan Valley." *DIRASAT*, University of Jordan, Amman, Jordan. 1988.

Safadi, A.S. "Irrigation Scheduling of Squash Under Drip Irrigation and Black Plastic Mulch in the Central Jordan Valley." M.S. Thesis, University of Jordan, Amman, Jordan. 1987.

ALLEN MATKINS LECK GAMBLE & MALLORY LLP
DAVID L. OSIAS
JEFFREY R. PATTERSON
MARK J. HATTAM
501 West Broadway, Ninth Floor
San Diego, California 92101-3577
Phone: (619) 233-1155
Fax: (619) 233-1158

HORTON, KNOX, CARTER & FOOTE
JOHN PENN CARTER
895 Broadway, Suite 101
El Centro, CA 92243
Telephone (760) 352-2821

Attorneys for Petitioner
Imperial Irrigation District

Corrections Inserted

STATE WATER RESOURCES CONTROL BOARD

STATE OF CALIFORNIA

IMPERIAL IRRIGATION DISTRICT and SAN DIEGO COUNTY WATER AUTHORITY,

Petitioners.

NOTICE OF ERRATA REGARDING IID EXHIBIT 2 (PHASE 1)

Attached hereto are corrections to IID Exhibit 2. Please replace the following pages in Appendix 7 of that Exhibit:

pp. 6-11, and p. 2 to the Field No. 10 Field Irrigation Evaluation Data Summary section (which is found following the text and photos of Appendix 7).

Dated: April 9, 2002

ALLEN MATKINS LECK GAMBLE & MALLORY LLP

By: ______________________

MARK J. HATTAM
Attorneys for Petitioner
Imperial Irrigation District

NRCE

ASSESSMENT OF IMPERIAL IRRIGATION DISTRICT'S WATER USE

NATURAL RESOURCES CONSULTING ENGINEERS, INC.®

Civil, Environmental, and Water Resources Consultants

NRCE®

ASSESSMENT OF IMPERIAL IRRIGATION DISTRICT'S WATER USE

NATURAL RESOURCES CONSULTING ENGINEERS, INC.

CIVIL, ENVIRONMENTAL, AND WATER RESOURCES CONSULTANTS

Colorado Office
131 Lincoln Avenue, Suite 300
Fort Collins, Colorado 80524
(970) 224-1851/FAX (970) 224-1885

California Office
1250 Addison Street, Suite 204
Berkeley, California 94702
(510) 841-7814/FAX (510) 841-3728

Albuquerque Office
317 Commercial N.E., Suite 102
(505) 244-1588/FAX (505) 244-1589

East Africa Office
P.O. Box 5260
Ras Dashen Street, #5
Asmara, Eritrea
011-291-1-120574/FAX 011-291-1-120629

March 2002

TABLE OF CONTENTS

I. INTRODUCTION I-1
II. OVERVIEW OF IID AND ITS IRRIGATION II-1
- A. The Colorado River II-1
- B. IID's Water Delivery System II-4
  - 1. Imperial Dam II-5
  - 2. All American Canal II-7
  - 3. East Highline Canal II-7
  - 4. Central Main Canal II-7
  - 5. Westside Main Canal II-8
  - 6. Briar and New Briar Canal II-8
  - 7. Rositas Canal II-8
  - 8. Vail Canal II-8
  - 9. Canal Laterals II-8
  - 10. Drainage II-8
  - 11. Regulating and Interceptor Reservoirs II-9
- C. Water Ordering and Canal Delivery Operations II-9
  - 1. Water Scheduling Within IID II-10
  - 2. 12- and 24-Hour Delivery Period II-11
  - 3. Daily Canal Operations II-12
  - 4. Summary of IID Delivery Operations II-14
- D. IID's On-farm Irrigation Systems II-14
- E. IID Soil Preparation II-17
- F. Seed Germination and Crop Establishment in IID II-17
- G. Leaching Requirement II-18

III. CLIMATIC EFFECTS ON IID IRRIGATION III-1
- A. General Weather Conditions III-1
- B. Reference Crop Evapotranspiration (ET_o) III-3
  - 1. CIMIS Data III-3
  - 2. ET_o Estimation Methods III-3
- C. Crop Evapotranspiration III-4
  - 1. Single Crop Coefficient Approach III-4
    - a. Crop Characteristics III-5
    - b. Crop Growth Stages III-5
    - c. Climatic Conditions III-8
- D. Cropping Patterns, Acreage, and Growing Seasons III-9
  - 1. Cropping Patterns and Acreage III-10
  - 2. Growing Seasons III-11
- E. Effective Precipitation III-11
- F. Net Irrigation Requirement III-12
  - 1. Diversion Requirement III-14

IV. THE NATURE OF IID'S SOILS CREATES AN INCREASED WATER NEED IV-1
- A. Previous Studies Related to the Behavior of IID Cracking Soils Support the Need for Tailwater for Horizontal Leaching IV-1

B. IID Tailwater Studies IV-14
C. Irrigation Efficiency and Salinity Management IV-15
1. Heavy and Medium Soils IV-15
2. Sandy Soils IV-16
3. Leaching/Land Preparation Irrigation on Heavy Soils IV-17
4. IID Soil Analysis IV-20
D. Parameters That Should be Considered When Estimating Leaching Requirements for Crops Grown in the Heavy Cracking Soils of IID IV-23
1. Tailwater as a Leaching Component IV-23
2. Leaching Fraction as a Function of Field Length IV-24
3. Vertical Leaching Comparison IV-24
E. Estimation of Leaching Requirements IV-24
1. Horizontal Leaching Effect of Cracked Soils IV-25
2. Vertical Leaching on Heavy-cracking Soils IV-26
3. Vertical Leashing Between Crops IV-26
4. Leaching During Crop Irrigation IV-26
F. Application of Field Irrigation Evaluations to IID Drainage IV-26
V. IID'S WATER BUDGET V-1
A. IID's Water Budget V-1
1. Boundaries of IID Controlled Volume Study Area V-1
2. Inflow V-2
3. Outflow V-3
4. Storage Changes V-4
5. IID Water Consumption V-4
a. Other Water Uses in IID V-5
b. Non-Agricultural Consumption V-6
c. Canal and Reservoir Evaporation V-6
d. Evaporation From Drains and Rivers, and Phreatophyte ET V-6
e. ET From Rainfall on Non-agricultural and Agricultural Land V-7
f. Reference Crop Evapotranspiration (ET_o) V-7
g. Land Areas V-7
6. Results of Water Volume Balance V-8
a. Canal Subsystem Water Budget V-13
b. Inflow V-13
c. Outflow V-13
(1). Canal Seepage V-13
(2). Spills V-13
7. Results of Canal Subsystem Water Balance V-14
B. On-farm Subsystem Water Budget V-16
1. Inflow for Agricultural Lands V-17
2. Outflow for Agricultural Lands V-17
3. Results of Water Volume Balance V-17
C. Irrigation System Performance V-20
1. Overall Irrigation System Efficiency V-20

2. Distribution System Efficiency V-23
3. On-farm Irrigation System Efficiency V-25
4. Irrigation Water Use Efficiency Comparisons V-26
a. Distribution System Efficiency V-26
b. On-farm Irrigation System Efficiency V-27
c. Overall Irrigation System Efficiency V-29
D. Review of Other IID Water Use Assessment Reports V-29
1. 1995 Jensen Report V-30
2. 1997 Draft Jensen-Walter Report V-31
3. Summary V-36
VI. ADDITIONAL WATER CONSERVATION OPPORTUNITIES VI-1
VII. THE PROPOSED TRANSFER WILL NOT INJURE JUNIOR WATER RIGHTHOLDERS VII-1
A. IID/SDCWA Water Transfer Agreement VII-1
B. Colorado River Flow Information VII-2
1. Diversions and Return Flows VII-2
a. Parker Dam to Imperial Dam VII-2
b. Imperial Dam and East Highline Canal Turnout VII-4
2. Analysis of 200,000 Acre-foot Reduction due to Transfer VII-9
a. Flow Adequacy VII-11
(1) Flow Accounting System on the Colorado River VII-11
(2) Daily Flow Analysis on the Colorado River VII-12
(3) Flow Accounting System on the All American Canal VII-13
(4) Daily Flow Analysis on the All American Canal VII-13
b. Hydraulic Limitation VII-14
(1) Reach on the Colorado River VII-14
(2) Reach on the All American Canal VII-16
VIII. CONCLUSION VIII-1

LIST OF TABLES

Table II-1	Annual Average Colorado River Flows and Salinity Levels at Lee's Ferry and at Imperial Dam From 1971-1997	II-3
Table II-2	IID Constructed Reservoirs	II-9
Table II-3	Soil Salinity Thresholds for IID Crops (ASCE, 1990)	II-19
Table III–1	Published FAO#56 Single Crop Coefficients for Standard Conditions and Adjusted Crop Coefficients for the Conditions of the Imperial Valley	III-7
Table III-2	Weighted Average Monthly Precipitation (Inches) in IID (1988-1997)	III-12
Table III-3	Annual Volumes (Acre-feet) of Crop Evapotranspiration (ET_c), Effective Precipitation (EPg), and Net Irrigation Requirement (NIR) (1990-1997)	III-13
Table III-4	Annual Volumes (Acre-feet) of the Reduced Crop Evapotranspiration (ET_c), Effective Precipitation (EPg), and Net Irrigation Requirement (NIR) (1990-1997)	III-14
Table IV-1	Leaching Fraction for Soil Series in IID	IV-6
Table IV-2	Inflow and Outflow of Irrigation Water and Water Qualities	IV-14
Table IV-3	Total Salts Introduced and Removed by Tailwater	IV-14
Table IV-4	Summary of Irrigation Data for Seven Irrigation Evaluations on Fields With Heavy and Medium Soils (Fields 1, 2, 3, 6, 7, 8, 9)	IV-16
Table IV-5	Summary of Irrigation Data for Irrigation Evaluation on Field With Sandy Soil (Field 4)	IV-17
Table IV-6	Summary of Irrigation Data for Leaching Irrigation Evaluation on a Field With Heavy Soils (Field 10)	IV-17
Table IV-7	IID Soils Within Irrigated Boundary Sorted by Permeability of Top Soil Layer	IV-21
Table IV-8	IID Soils Within Irrigated Boundary Sorted by Permeability of Limiting Layer in the Top Four Feet	IV-22
Table IV-9	Disposition of On-farm Leaching and Deep Percolation in IID (Typical Year)	IV-27
Table IV-10	On-farm Water Balance (Average of 1988 Through 1997)	IV-28

Table V-20 Irrigation Distribution System Efficiency of Various Projects According to the USBR (1990). V-27

Table V-21 On-farm Irrigation System Efficiency of Various Irrigation Districts (%) According to the USBR (1979).......... V-28

Table V-22 Estimated Annual Leaching.......... V-32

Table V-23 Estimated Irrigation Consumptive Use From Water Balance.......... V-34

Table V-24 Estimated Tailwater not Used for Leaching and Excess Deep Percolation.......... V-35

Table VII-1 Diversions and Returns (Acre-feet) on the Colorado River Between Parker and Imperial Dams VII-5

Table VII-2. Design Configuration and Operating Criteria for the AAC Turnout Structures and Historical Canal Flows and Diversions (1988-1997).......... VII-17

LIST OF FIGURES

Figure II-1 Imperial Irrigation District Water Transportation: Hoover Dam to User II-6

Figure III–1 Long-term Average Monthly Maximum, Minimum, and Mean Air Temperatures (1928–1997) in Brawley, California. III-2

Figure III–2 Long-term Average Monthly Precipitation (1928-1997) in Brawley, California III-2

Figure III-3 Typical Single Crop Coefficient Curve With its Four Stages of Growth. III-6

Figure IV-1 Water Infiltration Patterns for Surface Irrigation IV-13

Figure IV-2 Salt Accumulation for Heavy Soils During Sugar Beet Production for Field 10 .... IV-19

Figure IV-3 Distribution of On-farm Water Deliveries (Average of 1997 & 1998). IV-30

Figure V–1 Schematic Diagram of IID's System Wide Water Volume Balance With Total Water Consumption as the Closure Term V-2

Figure V-2 Schematic Diagram of IID's System Wide Inflow and Outflow With Water Consumption on Agricultural Land as a Closure Term V-5

Figure V-3 Water Volumes for the Components of IID's System-wide Water Balance. ... V-11

Figure V-4 Relative Percentages of Water Volume for IID's System-wide Balance Components V-12

Figure V-5 Schematic Diagram of IID's Canal Subsystem Water Volume Balance and its Components V-13

Figure V-6 Water Volumes for the Components of IID's Canal Subsystem Water Balance V-15

Figure V-7 Schematic Diagram of the On-farm Subsystem Water Volume Balance and its Components V-17

Figure V-8 Water Volumes for the Components of IID On-farm Subsystem Water Balance Using Total Irrigation Water Delivery Based on the Canal Subsystem Water Balance to Estimate Tailwater and Deep Percolation V-18

Figure V-9 Water Volumes for the Components of IID's On-farm Subsystem Water Balance Using IID Reported Total Irrigation Water Delivery Volume to Estimate Tailwater and Deep Percolation V-19

Figure V-10 Relative Percentages of Water Volumes for IID On-farm Subsystem Water Balance Components V-19

Figure V-11 Comparing Cumulative Canal Lining With Percentage of Canal Seepage Losses With Respect to Total Canal Inflow V-24

Figure V-12 On-farm Leaching Estimates Based on 1997 Jensen-Walter, Boyle, Water Study Team, and NRCE Water Balance V-33

Figure V-13 Tailwater not Used for Leaching and Excess Deep Percolation Estimates Based on 1997 Jensen-Walter, Boyle, Water Study Team, and NRCE Water Balance V-35

Figure VII-1 Schematic Diagram of Diverters for the Study Area VII-3

Figure VII-2 Locations of Streamflow Gaging Stations for the Study Area Below Hoover Dam VII-10

Figure VII-3 Side Views of a Typical Turnout on the AAC VII-18

Figure VII-4 Minimum Operating Water Surface Elevation for the Turnouts on the AAC and the Water Surface Elevations of the AAC at Imperial Dam and Pilot Knob Check Structure at Minimum Flow VII-19

I. INTRODUCTION

Imperial Irrigation District (IID) is a large irrigation district located in the Imperial Valley of Southern California, near the Colorado River and the Arizona border. IID is in charge of ordering and distributing approximately 3.2 million acre-feet of water from the Colorado River every year. IID's irrigation system is large and complex and includes the 82-mile All American Canal (AAC) as well as almost 1,700 miles of other canals, numerous reservoirs, over 1,400 miles of drain ditches, and almost 33,600 miles of tile drains.

The primary objective of this study by Natural Resources Consulting Engineers, Inc. (NRCE) was to evaluate the overall agricultural water uses within IID and determine whether such water uses are reasonable and beneficial. In addition, NRCE evaluated whether the proposed transfer by IID of up to 200,000 acre-feet per year of conserved water to the San Diego County Water Authority (SDCWA) would have an adverse impact on junior water right holders on the Lower Colorado River.

NRCE conducted a detailed analysis of IID's water supply, demand, delivery systems and irrigation, using records from 1988 to 1997 as well as a comparative water use study of several irrigation districts located within the Southwest and the Lower Colorado River Basin. NRCE also conducted its own field evaluation in the summer of 2000.

NRCE has concluded that IID's agricultural water uses are reasonable and beneficial. Despite its unique environmental conditions, IID has one of the highest on-farm irrigation efficiencies relative to the other irrigation districts served by the Lower Colorado River, and has a higher on-farm irrigation efficiency than the assumed expected efficiency by the State of California for the year 2020. According to a United States Bureau of Reclamation (USBR) study conducted in the late 70s, the on-farm irrigation efficiencies for the various irrigation districts in the Lower Colorado Basin ranged from 32 to 78%, and IID had the highest average on-farm efficiency of 78%. NRCE also determined that IID's proposed diversion of 200,000 acre-feet of conserved Colorado River water would have no meaningful adverse impact on other water right holders downstream of the proposed Lake Havasu diversion.

In evaluating IID's water use, NRCE considered the available water supply, water quality, and the major facilities that convey and distribute irrigation water to IID. In addition, NRCE analyzed the water requirements for the various crops grown in the District, taking into account the climate and the agricultural land resources of IID, and IID's delivery system.

IID's water use was first analyzed by NRCE using the water balance method. A volume balance analysis was performed for the entire District as a system-wide unit, as well as two subsystems that include the conveyance and distribution level subsystem and the on-farm level subsystem. The primary objective in the water balance method approach is to estimate the total water consumptive use. This method is appropriate for the Imperial Valley because of the Valley's unique physical setting and hydrogeologic conditions as a closed basin.

Determination of the on-farm and overall irrigation system efficiencies required examination of irrigation water beneficially used. There are various uses of irrigation water that are beneficial in addition to directly satisfying crop water demands. In IID, other beneficial uses of irrigation water include seedbed and land preparation, germination, cooling, and leaching for salinity control.

After completing its study, NRCE determined the following:

- During the study period (1988-1997), IID's on-farm efficiency averaged 83%, while its overall efficiency was about 74%. In other words 83% of the delivered water to the headgates was used for crop evapotranspiration (ET), leaching, and other crop production uses. The California Department of Water Resources (CDWR) assumes that statewide on-farm irrigation efficiency will be 73% by the year 2020 and could reach 80% through better irrigation management and improved facilities (CDWR 1998). The irrigation efficiency of IID has thus already surpassed the State's future efficiency estimate, 20 years ahead of time. To attain such irrigation efficiency, IID growers often apply lower amounts of water than they really need, thus limiting tailwater, but also accepting lower yields.

- The irrigation efficiency of IID is so high that even those irrigation projects that are served with some of the most technologically advanced irrigation systems, including drip irrigation, exhibit about the same level of irrigation efficiency. To the extent that water loss occurs, it is generally justified as a corollary to farming in a hot climate with heavy cracking soils.

- Based on the data assembled for NRCE's water budget study, IID's conveyance and distribution efficiency was determined by dividing the irrigation water delivered to the farms by the net supply of irrigation water to all the canals off the AAC. The average conveyance and distribution efficiency from 1988 to 1997 was determined to be approximately 89%. In other words, about 11% of the water diverted from the AAC was lost to evaporation and unrecovered seepage and spills before the irrigation water reached the farm headgates. The 89% conveyance efficiency is high, especially given the size of IID's irrigation project and the complexities of its water distribution system management.

- Tailwater is a vital and necessary component of the Imperial Valley's irrigation practice. Due to the low permeability of the heavy cracking soils in IID, it is difficult to adequately leach salts from the soil during regular irrigation applications. The nature of most of IID's soils requires more leaching water than stated in traditional formulae, of which the equations are more applicable to non-cracking heavy soils. Though both horizontal and vertical leaching occur during regular irrigation, only about 52% of the salts in the soil are leached at such time, while the other 48% remain in the root zone, requiring additional leaching between crops.

- During regular irrigation on IID's medium and heavy soils, only 4.5% of the applied water drains vertically, removing about 30% of the salt introduced by the irrigation water, while about 17% of the applied water ends up as tailwater that removes approximately 22% of the salt introduced by the irrigation water. This leaching process is compounded by the fact that the Colorado River, by the time it reaches IID, contains significantly increased mineral salt concentrations. Excess salts in light soils are more easily removed than salts in heavy cracking soils, such as those found in IID, because the permeability of the light soils is adequate for vertical leaching.

- On many IID farms with medium and heavy cracking soils, it would be best for growers to apply even more water during irrigation for leaching and crop consumptive use purposes than they currently do, because this would increase crop yields. However, since higher water application could result in higher tailwater, growers tend to apply barely enough water for crop use and for partial leaching of salts. As a result of insufficient leaching, the lower end of the field becomes too saline for crop production, thus decreasing the productivity of valuable acreage.

- When irrigation water is applied at the head of the field, it picks up salts from the soil as it moves to the lower end of the field. It was determined that the salinity of the tailwater is about 30% higher than the water delivered at the head of the field, which indicates significant horizontal leaching is taking place in IID because of the nature of its soils.

- Considering the three processes of leaching for cracking soils (vertical leaching during crop irrigation, leaching irrigation, and horizontal tailwater leaching), it was determined that approximately 0.73 acre-feet per acre is used for leaching on an annual basis. The leaching requirement for light soils was estimated to be about 0.58 acre-feet per acre per year. About 87% of IID irrigated lands have limited permeability in the root zone, while the remaining 13% are light soils.

Based on the above results and the other matters addressed in this report, it is NRCE's opinion that the overall irrigation water use in IID is reasonable and beneficial. Though IID has been criticized by some for its water use, in NRCE's opinion such criticisms are uninformed and unjustified. A reasonable look at IID's water usage shows that IID and its growers manage reasonably well in difficult environmental circumstances, and in fact could justify using more water for leaching and crop consumptive use than they currently utilize.

REFERENCES:

California Department of Water Resources. (1998). *The California water plan update bulletin 160-98 Volume 2.* Department of Water Resources, State of California, Sacramento, California, p.6-12.

II. OVERVIEW OF IID AND ITS IRRIGATION

In this section, a general overview of IID and its irrigation is presented. The following chapters contain a detailed analysis of IID's agricultural water usage.

A. The Colorado River

The main water source for irrigation and municipal uses within IID is the Colorado River.

Water is diverted from the Colorado River at Imperial Dam for use in IID and is conveyed by the AAC. The AAC runs west for about 82 miles just north and approximately parallel to the border of Mexico. Although a large portion of the sediment carried by the Colorado River is intercepted by a system of reservoirs upstream of Imperial Dam, a substantial amount of silt is nevertheless carried by the river flow downstream of the major Colorado River reservoirs. To reduce the amount of sedimentation diverted via Imperial Dam, a series of desilting basins are employed. These basins remove about 70,000 tons of silt per day from the Colorado River water prior to diversion into the AAC. The desilted water flows past the Pilot Knob check structure, where a portion of the water returns to the river to satisfy water needs for Mexico. A gauging station has been installed just downstream of the Pilot Knob check structure to measure the flow in the canal.

The AAC serves IID and the Coachella Valley Water District (CVWD) and has a capacity of about 15,515 cubic feet per second (cfs). Towards the end of the canal, near the Westside Canal, its size shrinks to about 2,665 cfs. Almost all of IID's water has been supplied through the AAC since 1942. The AAC is an earthen canal with no artificial lining for reducing seepage losses of water. The maximum canal width at the water surface is 232 feet, having a depth of about 20.6 feet and a bottom width of 160 feet. Upstream of the first major diversion from the AAC to IID (at the EHL Canal), water is diverted to the Coachella Canal to serve CVWD. The amount of water diverted to the Coachella Canal is approximately 10% of the total IID diversion amount.

Although the Colorado River water is a blessing to the dry Southwestern United States, it also carries a large amount of unwanted dissolved salts. The amount of salt carried by the Colorado River increases as it flows downstream. At its headwaters, the Colorado River has a salinity concentration of about 80 microsiemen per centimeter (µs/cm). At Imperial Dam, the salt concentration is about 1,200 µs/cm in recent measures. Return of irrigation drainage water to the river is one cause of the increase in salinity. When water is diverted from the Colorado River for irrigation, a large portion of the return flow from the irrigated lands returns to the river while some becomes groundwater recharge and some is lost to crop evapotranspiration (ET). Natural factors, such as various geologic formations, contribute to the increase in salinity as well. Salt addition to the river from natural sources, plus the effects of evaporation and the use of water from the river system, results in an increased concentration of salts as the river flows downstream. Therefore, because the water available to IID at Imperial Dam has already been used and reused many times, it contains a higher salinity concentration than points upstream. Colorado River water at Imperial Dam has an average salinity of more than one ton of salt per acre-foot. Drainage water from the Imperial Valley, with a salinity of about 4 tons per acre-foot (Total Dissolved Solids (TDS) of about 3,000 ppm), enters the Salton Sea.

The river salinity level just above Imperial Dam was compared to the salinity at Lee's Ferry, which is approximately 640 miles upstream, to illustrate the salinity concept mentioned above The United States Geological Survey (USGS) has been monitoring the flow as well as the salinity level at Lee's Ferry (USGS gage #938000) and above Imperial Dam (USGS gage #9429490) for many years. The salinity level of the Colorado River water at Imperial Dam was not measured until 1971. The historic salinity of the Colorado River at Lee's Ferry and at Imperial Dam, since 1971, are shown on Table II-1.

As one can see from Table II-1, the Imperial Dam diversion point on the Colorado River has considerably more salinity than that at Lee's Ferry. The average salinity at Lee's Ferry and Imperial Dam for the period from 1971-1997 are 0.828 and 1.224 ds/m, respectively. The average flows at Lee's Ferry and above Imperial Dam are 14,802 cfs and 10,719 cfs, respectively. The average river flow decreased by 28% between Lee's Ferry and Imperial Dam, while the salinity level increased by 48%.

Due to the high salinity levels of the Colorado River water, IID's growers need to apply water in excess of the amount required for ET in order to maintain acceptable soil salinity. The effects of the highly saline irrigation water from the Colorado River are compounded by the nature of the heavy cracking soils of IID, which require a higher water application, compared to lighter soils, to leach the salts below the root zone. This will be discussed in detail in later sections of this report.

Table II-1 Annual Average Colorado River Flows and Salinity Levels at Lee's Ferry and at Imperial Dam From 1971-1997.

Year	Lee's Ferry (#09380000)		Above Imperial Dam (#09429490)	
	Salinity (ds/m)	Flow (cfs)	Salinity (ds/m)	Flow (cfs)
1971	0.858	12,788	1.431	8,071
1972	0.863	12,873	1.356	8,155
1973	0.889	12,492	1.334	7,844
1974	0.865	12,276	1.330	8,713
1975	0.832	12,377	1.310	8,329
1976	0.846	12,948	1.312	8,338
1977	0.891	10,157	1.310	7,978
1978	0.940	12,440	1.322	7,870
1979	0.912	11,201	1.304	8,092
1980	0.842	15,605	1.234	11,538
1981	0.843	10,840	1.295	10,544
1982	0.913	12,454	1.280	7,504
1983	0.821	26,497	1.191	17,359
1984	0.752	28,065	1.087	27,403
1985	0.663	23,326	0.982	22,542
1986	0.679	25,819	0.926	20,321
1987	0.710	15,905	0.999	14,315
1988	0.817	10,811	1.072	9,533
1989	0.757	11,074	1.140	8,311
1990	0.861	10,914	1.168	8,287
1991	0.921	11,581	1.243	7,924
1992	0.921	11,025	1.223	7,129
1993	0.897	11,391	1.230	6,554
1994	0.797	11,095	1.280	8,169
1995	0.807	14,096	1.260	7,692
1996	0.732	15,235	1.270	8,354
1997	0.719	21,099	1.147	10,318
Average	0.828	14,802	1.224	10,719

Data sources for the above data are:
National Climatic Data Center (NCDC) EarthInfo CD (1995)
USGS Water Resources Data Books (1961-1970)
USGS Office in Tempe, AZ (1999).

B. IID's Water Delivery System

IID has utilized its state and federal water rights for almost a century to irrigate the Imperial Valley, turning a near-desert region into a highly productive farmland. IID operates and maintains most of the water diversion, conveyance, and distribution systems that deliver Colorado River water to 461,706 acres of irrigated and idle lands as well as to municipal customers within the Imperial Valley. The control of this water begins at Hoover Dam, where ordered water is released by the USBR. IID's water supply is therefore an upstream-controlled system in which the Colorado River serves to convey water from Hoover Dam to Imperial Dam, a distance of 300 miles. The diversion at Imperial Dam includes a number of related components which consist of the dam itself, the AAC headworks and desilting basins, the California sluiceway, Gila Gravity Main Canal Headworks, Senator Wash Dam and Reservoir, and Laguna Dam. The USBR constructed and owns all these facilities.

From the diversion at Imperial Dam, water flows down the AAC a distance of 53 miles until the flow is split between the EHL Canal and the continuing branch of the AAC. From these canals, water is distributed throughout the districts of Holtville, North, and Southwest Divisions by means of six main canals: EHL, Central Main, Westside Main, Briar/New Briar, Rositas and Vail, as shown on Plate II-1. This distribution system is owned and operated by IID and includes seven regulating reservoirs and three interceptor reservoirs. The system also includes 430 control structures, about 1,400 miles of open drain, and 33,600 miles of buried drainpipe (or tile drains).

A few things that distinguish IID from the other districts on the Lower Colorado River are its distance from the upstream point of control and diversion, the fact that the overwhelming majority of its irrigated lands have very low permeability and crack when dry, and its reliance on a single source of water. CVWD is also distant from the point of diversion on the Colorado River, but only Improvement District #1 within CVWD receives Colorado River water for irrigation. CVWD, as a whole, derives a portion of its irrigation water from groundwater sources, whereas IID derives no significant amount of irrigation water from groundwater or sources other than the Colorado River. Because of this reliance, IID operates under a very difficult set of water supply conditions that are not shared by other districts.

All of IID's daily water orders must be anticipated a minimum of four days in advance and are released 400 miles upstream from the place of use. Normally, upstream-controlled systems are not capable of perfectly matching supply with demand. Operation of this type of irrigation system requires more water to be released at the point of control (Hoover Dam) than is needed to satisfy the order. The only way to overcome this problem is to create significant storage facilities within the local portion of the conveyance and distribution system, and thus change the control of the system from upstream to downstream, or at least minimize the travel time of water orders. IID has accomplished some of this by the construction of regulating reservoirs that help compensate for inevitable problems in delivery quantity and timing. However, these facilities do not have the capability to store several days supply; thus, IID is still under upstream control.

Within IID, the process of a water order is based on staff estimates of demand. These estimates are based on historical demand, weather conditions, and cropping patterns. These factors and judgment form the basis for coordination of water releases made by the USBR. Normally, growers order water from IID one to two days in advance of delivery, and water orders are available to the irrigators, in 12-hour time blocks at a set flow rate determined by IID.

IID's complete water balance includes input from the AAC, the Alamo and New Rivers, precipitation, and a very small portion of groundwater. However, the source of water for irrigated lands is the AAC and effective precipitation. The AAC irrigation water represents the sole source of salts introduced to the irrigated lands, as the flows from the Alamo and New Rivers are not diverted for field application.

Figure II-1 shows the process of how water becomes available to meet a particular water order (Imperial Irrigation District Water Transportation, Hoover Dam to User). This figure illustrates the path and time it takes the water to flow from Hoover Dam to a given field in IID.

Once irrigation water is applied to the fields, it is evaporated directly from the soil surface and is transpired by plants (evapotranspired), leaving the salts behind. The residual water remaining and draining from the fields therefore has a higher salt concentration than the original supply. It is essential that enough water remain after the ET process that significant drainage from the field is generated. Drainage water must carry away salts introduced by the irrigation water so that a balance of salt within the root zone of the soil is maintained that does not exceed the maximum tolerable concentration for the crops being grown. Drainage water from IID fields is collected by subsurface and surface drains that either enter the Salton Sea by direct pumpage, or empty into the New and Alamo Rivers, which eventually discharge into the Salton Sea.

1. *Imperial Dam*

Imperial Dam serves primarily as a water control structure for diversion and does not create significant storage itself. The original 85,000 acre-feet of storage capacity that resulted from the construction of the dam quickly filled with sediment; the dam can only be considered a water control structure, not a storage facility. Diversion from Imperial Dam takes place on both sides of the Colorado River. On the California side, 15,155 cfs capacity is available to the AAC, and on the Arizona side, 2,200 cfs capacity is available to the Gila Gravity Main. The dam can pass a flood flow of 180,000 cfs, which is described as the "assumed maximum flood." The water surface elevation of the pool is 23 feet above the river's normal water surface.